

## Fertigation in Arid Regions and Saline Soils

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Arid lands form more than half of the arable land that is managed for agricultural purposes on the planet. Arid lands are typically characterized as having <500 mm (less than 20 inches) of annual precipitation. Worldwide, these regions exhibit very diverse ranges of conditions and of plant and animal communities, i.e., they are characterized by considerable biological diversity. Soils of arid and semi-arid areas are mostly alkaline in nature and many are also salt and/or sodium (Na) affected. Soils of arid regions are typically very highly saturated in bases ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ). Soils in arid regions have played a unique role in history. The rise and fall of several ancient civilizations has been tied to irrigation systems and the subsequent management or mismanagement of these systems. Therefore, our knowledge of previous mistakes from other civilizations can enable us to avoid repeating errors in management of arid regions for agricultural purposes and irrigation systems in the future.

Because irrigation is an important factor in the management of agricultural systems in arid lands, the application of fertilizers and nutrient inputs in the irrigation water (fertigation) is a common and increasingly important practice. Fertigation provides an opportunity to optimize the efficiency of an agricultural production system with respect to water management and the input of fertilizer nutrients. There are several critical factors that need to be considered in connection with the management of arid region soils and the practice of fertigation, these include: 1) management of salinity and sodicity in soils; 2) knowledge of crop-specific water requirements, and appropriate water management; 3) the understanding and utilization of crop nutrient requirements; and 4) the integration of these factors in a systems management approach. This integrated approach should encompass, especially, management of the uptake and utilization of water and nutrients, and the management of soil salinity and sodicity with respect to the specific crops being grown.

Many arid regions are located in latitudes with warm or hot climates, therefore, they offer the potential for growing a very broad, diverse and productive range of crops. Irrigation systems are also highly varied in arid regions around the world, the most commonly used being surface and furrow irrigation. Other

common methods of irrigation include overhead sprinkler, drip, and border-surface flood irrigation. Each of these major types of irrigation systems encompasses several variations of methods. For example, furrow surface irrigation may involve application of irrigation water in every row or in alternate rows. The latter is quite commonly employed in relation to management of soluble salts in the beds.

Water quality is a critical factor with regard to the capacity and productivity of a given irrigation and crop production system. One of the primary factors associated with the quality of irrigation water is the amount of salt that it carries. The usual criterion for evaluating salinity with respect to water quality is the electrical conductivity ( $EC_w$ ), which is a common measure of the salt load and the salinity level, which might be critical in relation to a crop production system. The usual units of measurement are either decisiemens per meter (dS/m) or millimhos/centimeter (mmhos/cm); a saline soil is defined as one that has an EC of the soil extract ( $EC_e$ )  $>4$  dS/m. However, the growth of salt-sensitive crops, which include many vegetable crops, will be adversely affected at salinity levels below this definition level. In the application of fertilizers with the irrigation water, the management of soil salinity becomes increasingly critical, therefore, the quality of the irrigation water becomes a primary consideration. If the quality of the irrigation water is such that it carries fairly high concentrations of soluble salts, extra caution should be used in applying fertilizers with this irrigation water (fertigation). With respect to the irrigation water quality,  $EC_w$  values of  $<0.7$  dS/m will not present a problem or restrict the use of irrigation water. Waters with  $EC_w$  levels of 0.7-3 dS/m necessitate a slight to moderate restriction on irrigation use, and those with  $EC_w$  values  $>3$  dS/m pose a more serious or severe threat in this context. Thus, the application of fertilizers in irrigation water should be done in strict accordance with the quality of that water. The level of salinity in the irrigation waters must be recognized very quickly, and the impact of the addition of fertilizers on their salinity must be determined with respect to the introduction of the overall salt load into the field in question.

In all cases, water quality and the application of fertilizer nutrients need to be managed collectively to take account of the leaching process. The leaching fraction (LF) is, therefore, an important factor to be included in the overall irrigation requirements for the crop, above and beyond consideration of consumption by the crop. The interaction of the irrigation water with the fertilizers that are applied with these waters can be an important consideration with respect to the LF required for both short- and long-term management of the fields in question.

A saline soil is not a sodic soil; the latter is a non-saline soil that has a relatively large amount of exchangeable Na on the cation exchange complex (CEC), and it is defined as a soil having an exchangeable sodium percentage (ESP) >15. Another characteristic of a sodic soil is a sodium absorption ratio ( $SAR_e$ )  $\geq 13$ . A soil with a high concentration of exchangeable Na will tend to disperse, leading to a breakdown of soil particle flocculation; surface crusting is common. The end result is a reduction in infiltration and permeability which, in turn, reduces the effectiveness of the applied irrigation water and also of any nutrients that it may contain. Therefore, it is important to take into account the salinity and sodicity of a soil, when considering the application of fertilizer nutrients with the irrigation water. Very commonly, the source of the Na loading that can create sodic soil conditions in a field is the irrigation water. Fertilization practices that involve the irrigation water can also influence relative Na concentrations. If a soil becomes sodic the exchangeable Na needs to be reduced through the use and application of an amendment material. This can be done similarly to fertigation, particularly if the source of Na is in the irrigation water. If the irrigation water does not contain excessive amounts of Na the reclamation procedure with the amendment should involve direct applications to the soil. The most common approach to the reclamation of a sodic soil is by the application of soluble calcium (Ca) in the form of calcium sulfate ( $CaSO_4$ ). Calcium that is released from the  $CaSO_4$  exchanges with the Na on the cation exchange complex, thus removing the latter, as soluble Na, into the soil solution from which it must be removed by leaching. In arid regions, soils are commonly alkaline, with a high concentration of free calcium carbonate ( $CaCO_3$ ). Sulfuric acid ( $H_2SO_4$ ) can be applied in the irrigation water, similarly to fertigation. When the  $H_2SO_4$  enters the soil solution, the  $Ca^{2+}$  can be released from the  $CaCO_3$ , and can exchange with the Na on the exchange complex. The soluble Na can then be leached away and removed from the soil system. Therefore, management of both salinity and sodicity in a given field can be dealt with by means resembling fertigation practices.

## **Integration-System Management**

A good first step in integrating a crop production system, with regard to irrigation and nutrient management, is to acquire a good understanding of the crop growth and development patterns, as functions of heat units (HUs). A description of crop growth and development in relation to HUs and crop phenology forms the basis of an important method to standardize crop growth and development among different years and among many locations. The first step in developing a phenological guideline would be to look for critical stages of growth in relation to HU accumulation. These phenological guidelines can

then be used to describe crop water use or consumptive use patterns, as related to critical stages of growth. In addition, nutrient uptake patterns can be described in relation to HU accumulations and critical stages in crop growth and development. Thus, the common baseline for coordinating crop water use and crop nutrient uptake is provided in the form of a phenological timeline based on HU accumulations. Variations among seasons and locations with regard to HU accumulations can be better normalized by the use of actual HU calculations rather than days after planting (DAP), for example.

Not only is it important to understand the consumptive use pattern for a given crop, and how that relates to important stages in growth and development, and to maximum or total amounts of irrigation water used; it is also important to know what the optimum thresholds are, with respect to plant-available water (PAW) for the crop in question. Crops vary tremendously with respect to their thresholds and capacity to maintain optimum growth and development under varying levels of PAW depletion. For example, cotton and melon crops may be able to maintain adequate or optimum growth and development as long as the PAW is >55%, whereas other crops, such as lettuce, broccoli, cauliflower, chilies (and peppers in general), etc., will begin to suffer water stress and to limit their growth, development and yield, when PAW levels drop below 70%. Accordingly, it is important to have a quantitative assessment of these thresholds for each specific crop, and to be able to relate those thresholds to stages of growth and to provide suitable amounts of water by irrigation, as required for consumptive use. In addition, it is important to maintain a good quantitative assessment of PAW conditions in the field throughout all stages of growth, in order to optimize irrigation efficiencies and crop water use.

With respect to nutrient management and fertigation, nitrogen (N) is one of the most dynamic and important nutrients that must be considered with respect to overall crop management and fertigation. Interestingly, in terrestrial ecosystems, water is commonly the first most limiting factor after sunlight. In most arid regions sunlight is certainly not limiting, and water obviously becomes the first most limiting factor. That issue is addressed, of course, through our efforts to irrigate a crop and to provide for consumptive use, leaching, and overall crop needs. The next most limiting factor in a terrestrial ecosystem is commonly plant-available N. Accordingly, N is the fertilizer nutrient that is applied in the largest amounts and is required in the largest amounts by crop plants. The N cycle illustrates the many possible pathways and transformations associated with N in a soil-plant system. Therefore, we recognize the numerous potential routes of loss of N from the soil-plant system, in terms of leaching, denitrification, immobilization, volatilization, etc. Applications of fertilizer N

through the irrigation water offers an opportunity to split applications so as to increase and optimize N use efficiency in the crop production system.

In any crop production system it is important to understand the crop nutrient requirements specific to that crop. Similarly, it is important to be able to establish a realistic yield goal for the crop and field in question, in relation to total nutrient needs. This is particular true for mobile nutrients in a soil-plant system. For example, as a mobile nutrient, N presents a prime example of the need to establish a yield goal and an upper limit for crop N needs. For example, we know that cotton requires approximately 32 kg of N per bale (32 kg N/bale), therefore, a yield goal of six bales/ha for a given field would require a total of approximately 192 kg N/ha. This would be the total N need for the crop. The next step would be to subtract residual soil nitrate-N levels and the nitrate-N content in the irrigation water, to obtain the approximate target goal for N fertilization for the season, assuming that we are very efficient with fertilizer use and uptake.

To utilize N fertilizer most effectively in a soil-plant system, it is also important to understand the total N uptake for the crop, and the partitioning patterns among various plant components. For example, it is important to know the total uptake in a plant in relation to partitioning among the fruit and vegetative components, in order to achieve efficient crop nutrient management. From that information one can then determine the flux rates for the crop in relation to specific nutrient uptake. The flux information, i.e., the amount of N taken up per day, can provide an understanding of the stages of growth at which nutrient uptake is at its maximum, and how those nutrients might best be managed to achieve optimum efficiency and utilization by the crop.

With the phenological guideline information for the crop in question, and the information associated with nutrient uptake, e.g., with N uptake, in particular, and flux information for that nutrient, a strategy can be developed with regard to the timing of nutrient applications in relation to specific stages of crop growth and development, HU accumulations, and the flux points associated with that nutrient and crop. Providing for nutrient inputs within the period or growth stage at which maximum uptake occurs can maximize efficiency with respect to crop nutrient uptake and utilization. When nutrients are provided within this “optimal window” for application through the irrigation water, the real power and value of fertigation can be realized. Crops grown in arid regions offer tremendous opportunities, based on this level of water and nutrient management, to achieve the potential efficiency.

In aiming to optimize fertigation efficiencies there are two additional, very important points to consider with respect to the conservation of nutrients, particularly in arid and/or saline-soil environments. The first point is that of chemical precipitation. For example, a common method of N fertilizer applications in irrigation water has involved the introduction of anhydrous ammonia (AA) into the irrigation water, which then carries it into the field. However, precipitation reactions can take place that do not affect the availability of the N in the water, but that alter the water quality so that the relative concentrations of Na in the irrigation water are increased. This then contributes inadvertently to the development of a sodic soil, through a practice associated with fertigation. The chemistry of this process follows from the inclusion in the irrigation water of AA which, upon hydrolysis, forms ammonium hydroxide. The ammonium hydroxide then disassociates in solution releasing hydroxyl ions, that raise the pH of the irrigation water. When irrigation waters carry sufficient bicarbonate or carbonate, the precipitation of calcium carbonate ( $\text{CaCO}_3$ ) can follow quickly. Precipitation of  $\text{CaCO}_3$  from the irrigation water increases the relative concentration of the Na that is present in that irrigation water, and thus increases the SAR. This, in turn can lead to the development of sodic soil, soil dispersion, and reduced infiltration rates for the irrigation water. The end result is a sodic soil that has developed along with a reduction in the efficiencies of the irrigation and fertilization inputs to the field in question. Therefore, this practice should be avoided and/or balanced with appropriate additions of  $\text{H}_2\text{SO}_4$  or some similar acidic medium that can be added to the irrigation water with the AA.

Another potential mechanism of N loss from irrigation waters is volatilization. The volatilization of N from irrigation waters can be significant after the addition of any ammoniacal form of N fertilizer through fertigation. It is important to consider the interaction with the quality of the irrigation water and the potential for N loss from these waters through volatilization. In irrigation waters, high pH, high carbonate/bicarbonate concentration(s) and/or low concentration(s) of complementary ions such as sulfate ( $\text{SO}_4^{2-}$ ) can be important factors to consider with respect to water quality and chemistry. Experiments conducted in Arizona have shown that up to 30% of the N added as ammonium sulfate to a group of common irrigation waters can be lost through volatilization within 10 h of exposure in the irrigation water to temperatures of 30 to 35°C. These experiments also revealed losses of up to 50% of the added N when temperatures exceeded 30-35°C, and very rapid volatilization from ammonium sulfate ( $(\text{NH}_4)_2\text{SO}_4$ ; AS) fertilizer additions were measured at 40°C. This applied to a wide range of waters, of varied overall quality, but especially to irrigation waters that contained significant amounts of  $\text{SO}_4^{2-}$ -S. In such cases, this demonstrated a common ion effect, as encompassed by Le Chatelier's

Principle. For example, when AS was added to irrigation waters high in  $\text{SO}_4^{2-}$ -S, volatilization was reduced because of this common ion affect. However, it is essential to recognize the potential for volatilization in relation to the possibility of N loss from these irrigation waters in a very short period of time, particularly under warm or hot conditions. It is also important to note that warm and/or hot conditions are common in many arid regions where crop production systems employ fertigation. Therefore, application of ammoniacal forms of N in irrigation waters should be managed so that the exposure times in the field are minimized.

## **Conclusion**

Fertigation offers an opportunity to optimize a crop production system with respect to both irrigation and fertilization simultaneously. As discussed in this paper, important points to consider include an understanding of crop phenology, crop water use, nutrient uptake dynamics for the crop in question, and water quality interactions, as related to basic soil characteristics. For the best utilization and efficiency that can possibly be realized from a fertigation management approach, it is important to integrate these various factors into the overall management scheme for the soil-plant system. It is also important to be cognizant of the potential losses of nutrients (such as N) that are potentially inherent in irrigated systems in arid regions. Any crop production system in an arid region with saline soils must also include consideration of the basic principles of salinity and sodicity management, consistent with both short- and long-term sustainable goals.